Letters to the Editor

Towards Region-Specific, European Fate Factors for Airborne Nitrogen Compounds Causing Aquatic Eutrophication*

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In a recent contribution to this journal, FINNVEDEN and POTTING (1999) reviewed the state of the art for the impact category Eutrophication. Among other issues, important research needs identified are the general lack of fate modelling and spatial differentiation in the assessment of air emissions causing aquatic eutrophication. This letter outlines a first step towards fate factors to be used in the calculation of aquatic eutrophication potentials of ammonia (NH_3) and nitrogen oxide (NO_x) air emissions for Europe and a number of European regions.

In the characterisation phase of an LCA, the magnitude of the potential impact of individual eutrophying compounds towards aquatic eutrophication may be determined by

$$IS_{ae}=\sum_{e}\sum_{i}\sum_{x} CF_{ae,x,i,e}\times E'_{x,i,e} \tag{1}$$

IS_{ae} = Impact score for aquatic eutrophication per functional unit (kg PO_4^{3-}-eq.);

$CF_{ae,x,i,e}$ = Characterisation factor for aquatic eutrophication of compound x emitted to compartment e (air, water, soil) in region i (PO_4^{3-}-eq.);

$E'_{x,e,i}$ = Emission of compound x to compartment e in region i, per functional unit (kg).

Up to now, potential biomass production of phytoplankton per mass unit of compound x is generally used in Equation 1 as the aquatic eutrophication characterisation factor without a further differentiation between the initial emission compartments and regions involved (e.g. HEIJUNGS et al., 1992). However, only a fraction of the eutrophying air emissions will be transported to the aquatic environment, which may differ from region to region. It is this fraction that should be taken into account in the impact assessment procedure of aquatic eutrophication (SEPPÄLÄ, 1999). Therefore, introducing region-specific fate factors for airborne eutrophying pollutants in the calculation of aquatic eutrophication potentials will improve the current situation (Equation 2).

$$CF_{ae,x,i,air}=FF_{x,i,air\rightarrow aqua}\times EF_{ae,x} \tag{2}$$

$CF_{ae,x,i,air}$ = Characterisation factor for aquatic eutrophication of compound x emitted to the air in region i (PO_4^{3-}-eq.);

$FF_{x,i,air\rightarrow aqua}$ = Fate factor representing the fraction of compound x emitted to the air in region i that is transported to the aquatic environment (-)

$EF_{ae,x}$ = Effect factor representing potential biomass production of phytoplankton per mass unit of compound x relative to PO_4^{3-} (PO_4^{3-}-eq.).

The region-specific fate factor, $FF_{x,i,air\rightarrow aqua}$, consists of two separate pathways (Equation 3):

(1) direct deposition in the freshwater and marine environment ($FF_{x,i,direct,air\rightarrow freshwater}$ and $FF_{x,i,direct,air\rightarrow marine}$); and

(2) run-off to the aquatic environment after deposition on terrestrial systems ($FF_{x,i,indirect,air\rightarrow aqua}$).

Thus,

$$FF_{x,i,air\rightarrow aqua}=FF_{x,i,direct,air\rightarrow freshwater}+FF_{x,i,direct,air\rightarrow marine}+FF_{x,i,indirect,air\rightarrow aqua} \tag{3}$$

In this respect, the fraction directly deposited in the European marine environment ($FF_{x,i,direct,air\rightarrow marine,Europe}$) of airborne nitrogen compounds emitted in Europe may be modelled by using a Langrangian transport model as developed by EMEP/MSC-W (1996):

$$FF_{x,i,direct,air\rightarrow marine,Europe}=\frac{\sum_{j\in Europe} t_{i,j,x}\times E_{x,i}\times A_j\times K_{j,marine}}{E_{x,i}} \tag{4}$$

$t_{x,i,j}$ = Transfer coefficient, representing the part of emissions of pollutant x from region i that deposits on grid element j (mg $N.m^{-2}.kg\ N^{-1}$);

$E_{x,i}$ = Emission of substance x in region i (kg $N.year^{-1}$);

A_j = Area of European grid cell j (km^2);

$K_{j,marine}$ = Fraction of European grid cell j that is covered with sea water (-);

Transfer matrices were based on the results of a Langrangian model (EMEP/MSC-W, 1996), using input data of actual meteorological conditions and emissions for the years 1985 through 1995 (HUIJBREGTS, 1999). Region-specific emissions related to the year 1995 were taken from EMEP/MSC-W (1998).

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Table 1: Fate factors for direct deposition in the European marine environment of ammonia (NH_3) and nitrogen oxide (NO_x) emitted to air ($FF_{x,i,direct,\ air \rightarrow marine,\ Europe}$).

West-European regions	**NH_3**	**[a]NO_x**
Austria	$4.8.10^{2}$	$8.8.10^{2}$
Belgium	$2.3.10^{-1}$	$2.4.10^{-1}$
Denmark	$4.3.10^{-1}$	$2.9.10^{-1}$
Finland	$2.5.10^{-1}$	$2.0.10^{-1}$
France	$2.5.10^{-1}$	$2.3.10^{-1}$
Former Federal Republic of Germany	$1.4.10^{-1}$	$1.8.10^{-1}$
Former German Democratic Republic	$1.4.10^{-1}$	$1.6.10^{-1}$
Greece	$2.3.10^{-1}$	$1.8.10^{-1}$
Ireland	$4.6.10^{-1}$	$4.7.10^{-1}$
Italy	$2.1.10^{-1}$	$1.9.10^{-1}$
Luxembourg	$1.1.10^{-1}$	$1.7.10^{-1}$
Netherlands	$2.6.10^{-1}$	$2.8.10^{-1}$
Norway	$4.5.10^{-1}$	$2.8.10^{-1}$
Portugal	$2.3.10^{-1}$	$1.6.10^{-1}$
Spain	$1.6.10^{-1}$	$1.7.10^{-1}$
Sweden	$3.3.10^{-1}$	$2.4.10^{-1}$
Switzerland	$5.1.10^{-2}$	$9.4.10^{-2}$
United Kingdom	$4.3.10^{-1}$	$3.9.10^{-1}$
Baltic sea	x	$2.4.10^{-1}$
North sea	x	$3.5.10^{-1}$
N.E. Atlantic ocean	x	$4.3.10^{-1}$
Mediterranean sea	x	$5.1.10^{-2}$
East-European regions		
Albania	$1.9.10^{-1}$	$1.2.10^{-1}$
Belarus	$4.6.10^{-2}$	$7.9.10^{-2}$
Bosnia-Herzegovina	$8.6.10^{-2}$	$1.3.10^{-1}$
Bulgaria	$8.3.10^{-2}$	$1.2.10^{-1}$
Croatia	$1.6.10^{-1}$	$1.4.10^{-1}$
Czech Republic	$6.7.10^{-2}$	$1.1.10^{-1}$
Estonia	$2.4.10^{-1}$	$1.4.10^{-1}$
Hungary	$5.7.10^{-2}$	$1.0.10^{-1}$
Latvia	$1.6.10^{-1}$	$1.3.10^{-1}$
Lithuania	$9.5.10^{-2}$	$1.2.10^{-1}$
Macedonia	$3.9.10^{-2}$	$5.3.10^{-2}$
Moldavia	$7.7.10^{-2}$	$1.1.10^{-1}$
Poland	$9.7.10^{-2}$	$1.2.10^{-1}$
Romania	$6.0.10^{-2}$	$8.8.10^{-2}$
Russia (Kalingrad region)	$1.7.10^{-1}$	$1.4.10^{-1}$
Russia (Kola, Karelia)	$2.0.10^{-1}$	$3.6.10^{-1}$
Russia (St. Petersburg region)	$7.3.10^{-2}$	$1.0.10^{-1}$
Russia (Remaining)	$3.6.10^{-2}$	$4.6.10^{-2}$
Slovakia	$5.4.10^{-2}$	$8.8.10^{-2}$
Slovenia	$5.4.10^{-2}$	$8.0.10^{-2}$
Ukraine	$8.5.10^{-2}$	$9.7.10^{-2}$
Yugoslavia	$5.9.10^{-2}$	$9.4.10^{-2}$
European averages (1995)	**NH_3**	**NO_x**
West Europe	$2.4.10^{-1}$	$2.5.10^{-1}$
East Europe	$7.2.10^{-2}$	$8.9.10^{-2}$
Total Europe	$1.6.10^{-1}$	$2.1.10^{-1}$

[a] NO_x as NO_2; x = fate factor is not calculated

Grid cell areas were computed using calculation routines given by POSCH et al. (1999). Finally, the fraction covered with seawater was estimated per grid cell from the geographical map of the modelling domain as given in EMEP/MSC-W (1996).

The result of the modelling exercise is a set of fate factors related to the direct N deposition in the European marine environment due to air emissions of NH_3 and NO_x in 44 European regions (**Table 1**). Fate factors are not only given per European region, but also for West Europe, East Europe and the whole of Europe. These average fate factors were calculated by a weighted summation of the region-specific fate factors involved, using total region-specific emissions as weighting factors.

It should be noted that nitrogen deposition in the marine environment outside Europe due to airborne nitrogen emissions in European regions is not modelled by EMEP/MSC-W (1996) and therefore not included in the fate factors presented in **Table 1**. Transfer matrices of NO_x and NH_3 for the Northern hemisphere (e.g. GALPERIN et al. 1995; GALPERIN and SOVIEV, 1998) may be used for this purpose. Furthermore, the potential difference in sensitivity of marine ecosystems towards eutrophication is not taken into account in the current calculations, implying that nitrogen deposition in the marine environment is judged equally important for all marine ecosystems. However, a subdivision of the sensitivity of marine ecosystems may further increase the credibility of the aquatic eutrophication potentials for airborne nitrogen emissions.

Although still much work needs to be done in this research area, the fate factors presented here may be regarded as a first step towards the inclusion of a full fate analysis in the region-specific life cycle impact assessment of airborne emissions causing aquatic eutrophication in Europe.

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Eutrophication as an Impact Category

State of the Art and Research Needs

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Abstract. State of the art and research needs for the impact category eutrophication are discussed. Eutrophication is a difficult impact category because it includes emissions to both air and water – both subject to different environmental mechanisms – as well as impacts occurring in different types of terrestrial and aquatic ecosystems. The possible fate processes are complex and include transportation between different ecosystems. In some recent approaches, transportation modelling of air emissions has been included. However, in general, the characterisation methods used do not integrate fate modelling, which is a limitation. The definition of the impact indicator needs further research, too. The inclusion of other nutrients than those typically considered should also be investigated.